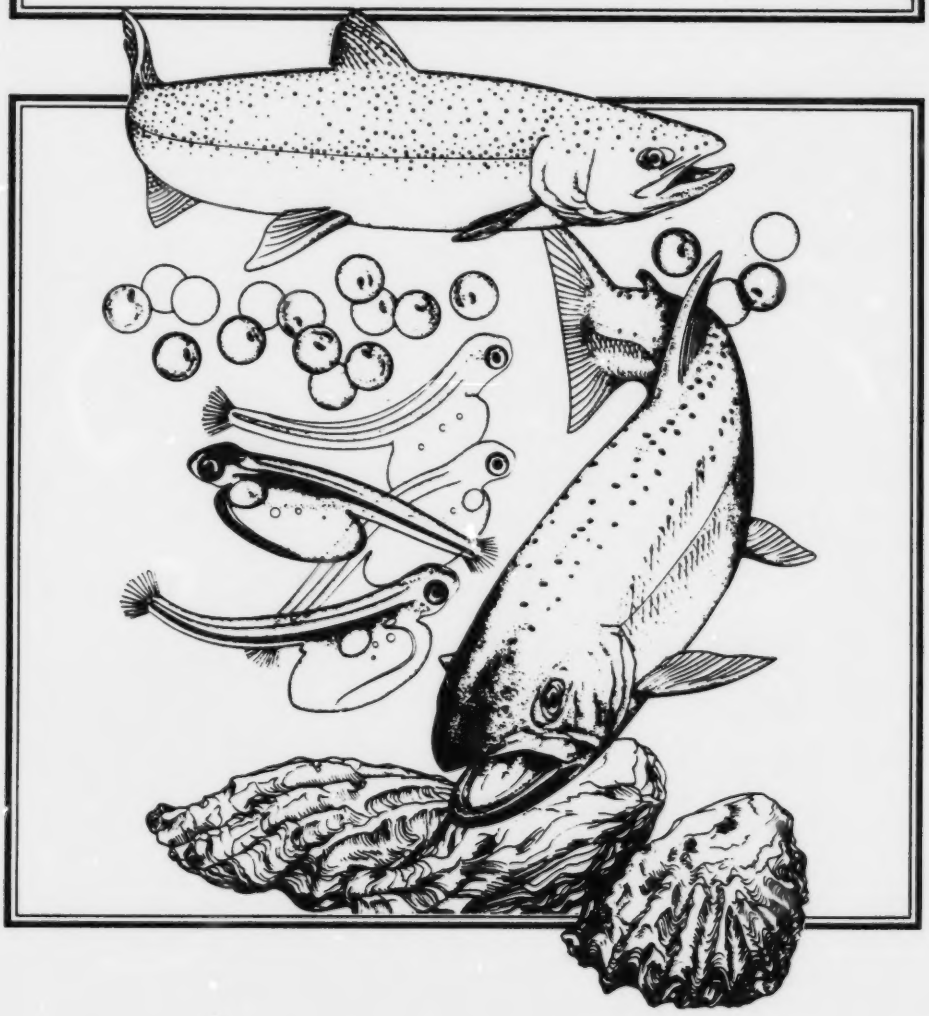
Aquaculture Industry Development Report

Freshwater Cage Culture in Scotland



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Aquaculture Industry Development Report

Study of Freshwater Cage Culture in Scotland

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Prepared for:

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Foreword

There is substantial interest in increasing the production capacity and reducing the production costs of smolts for salmon farming in British Columbia. Because of their minimum one year residency in fresh water, the available rearing space for Atlantic salmon will become scarse as their production volume expands. Additionally, the strategy of using S1 chinook rather than S0 will be feasible only if smolts are available in sufficient numbers at reasonable cost. This will depend on low cost expanded rearing capacity.

At present, the culture of smolts in netpens is practiced to only a small extent in British Columbia because of limited access to sites and the apparent unsuitability of many coastal lakes. Additionally, lake netpen culture is of concern to some government agencies due to possible conflicts with recreational users and wild fisheries. However, lake netpen culture is used to a significant extent in Europe, and particularly in Scotland, to solve questions of rearing space and production cost.

This report was prepared to summarize the Scottish experience with lake netpens to raise Atlantic salmon smolts and market-sized rainbow trout. Hopefully it will provide insight into expected costs and potential conflicts, as well as provide some direction to such activities in British Columbia.

Al Castledine, Victoria 1990

History of Freshwater Cage Culture in Scotland

Rainbow Trout Culture

The first commercial use of rainbow trout in freshwater cages in Scotland was in 1975. The Kames Fish Farming Company of Kilmelfort, Argyll used their own Kames cages to overwinter trout in Loch Lusgain-Mor. The zero aged fish were 5 grams when stocked in the summer and had grown to 80 grams the following May when they were stocked in seawater cages (Cannon, personal communication).

It did not take long for other operators to realize that trout could be grown right through to market size in excess of 250 grams in freshwater cages. Within 6 years of the original Kames trials in 1981, there were 18 freshwater cage sites in Scotland producing rainbow trout (Table 1).

The largest of these was Rothesay Sea Foods Ltd. on Loch Fad on the Island of Bute which, with approximately 200 tonnes annual production, by 1980 was the largest trout farm in Scotland. Other sites that within 10 years were to support over 200 tonnes of trout were established in Loch Earn, Loch Awe and Loch Kendoon. Interestingly enough, all these lochs are controlled by hydro dams as well as supporting major runs of migrating Atlantic salmon and seatrout.

The number of rainbow trout farms of all types peaked in Scotland in 1981 at 84 (Table 1). Between 1981 and 1986 annual output stagnated at around 2,200 tonnes because trout were selling at or below production costs of 50 - 60 pence/lb (Canadian $1.00 - 1.20/lb). Output expanded only on those farms that were growing trout cheaply. Significantly, the tonnage of trout raised from freshwater cage farms nearly doubled from 29% to 45% during this slack period for the industry between 1981 to 1986, although the number of freshwater cage farms had dropped back from 18 to 14 (Table 1).

After 1986 the output from trout farms in Scotland increased again, though, by 1989, the overall number of farms at 82 was still less than the number of farms in 1981 at 84. This increase in output was fueled by the establishment of the marketing cooperative "Scotrout" in 1984. This is a producer cooperative taking up some 80% of the Scottish output and selling it in an orderly manner in processed form direct to multiple retailers and the catering trade and avoiding as far as possible fickle wholesale markets and traders.

In 1989, 4 of the 16 freshwater cage sites yielded over 200 tonnes of trout. All 4 of these sites have been in existence for 10 years with continuous cultivation and no fallow periods.

With trout selling for an average price ex-farm of 90 pence/lb. (Canadian $1.80/lb) in 1989 the 1,482 tonnes that were produced were worth some Canadian $5.87M.

According to the D.A.F.S. statistics 151 persons were employed full-time and 85 part-time in the trout farming industry in 1989. If these figures can be divided pro rata between the various culture methods, this means that some 63 full time and 35 part-time workers were employed in freshwater cage culture of trout last year in Scotland.

Salmon Culture

Techniques for raising Atlantic salmon in freshwater cages followed on the earlier work with rainbow trout. The first commercial success was achieved by the second largest salmon farming company in Scotland, McConnel Salmon Ltd. In 1980, they raised potential two year old smolts in a small loch below their freshwater hatchery on the island of

Table 1: Rainbow Trout Production in Scotland

Year	#Freshwater Cage Sites (CS)	Total # Trout Farms	Tonnage Output (CS)	Total Tonnage	% Total
1981	18	84	656	2,261	29
1986	14	77	1,015	2,256	45
1989	16	82	1,482	3,512	42

Source: Reports of the Department of Agriculture and Fisheries for Scotland Annual Survey of Fish Farms.

South Uist in the Western Isles. In 1982, North Uist Fisheries Ltd. was founded to exploit this development. There are no rivers of substance on the Uists, and cage culture was the only way to expand smolt output for both salmon farming and ranching.

Since statistics were first recorded in 1984 by the Department of Agriculture and Fisheries for Scotland, development of freshwater cage culture has been explosive (Table 2).

Table 2: Salmon Smolt Production in Scotland

Year	No. Freshwater Cage Sites	Total # Sites	% of Total
1984	8	46	17
1985	22	66	33
1986	45	111	40
1987	51	131	38
1988	72	176	41
1989	70	168	42

Source: Department of Agriculture and Fisheries for Scotland Statistics.

From 1984 to 1986 the number of freshwater cage sites increased proportionately at an even greater rate than the rapid increase in tank sites. By 1986, about 40% of the freshwater salmon sites in Scotland were cage sites and it has remained at about this level ever since.

Since 1988, the actual number of smolts produced from freshwater cages has been recorded in the official statistics. As shown in Table 3, in both years over 50% of the salmon smolts raised in Scotland were produced from freshwater cages.

Table 3: Output of Atlantic Salmon Smolts from Tanks and Cages
(Numbers in Millions)

Year	# Freshwater Cages	# Freshwater Tanks	Total #	% Cages
1988	12.129	10.370	22.499	54
1989	13.498	12.328	25.820	52

Source: Department of Agriculture and Fisheries for Scotland Statistics.

Freshwater cage culture has been extremely significant in the expansion of salmon farming. This is particularly apparent from the examination of the two largest salmon farming companies in Scotland, Marine Harvest Ltd., and McConnel Salmon Ltd. Marine Harvest raised just over 8,000 tonnes of salmon in Scotland in 1989. This represents about 30% of the Scottish output of 28,553 tonnes.

Marine Harvest have been able to increase their annual smolt output from 0.5 million in 1980 to 4.5 million in 1987 without having to build a new hatchery or tank farm. The increase in output has been almost wholly due to freshwater cages.

Following the pioneering work on freshwater cages by McConnel Salmon Ltd. and North Uist Fisheries Ltd. in the Western Isles of Scotland there are now about 50 freshwater cage sites in this region of Scotland alone. Previously salmon growers in the Western Isle had to import the bulk of their requirements from large commercial smolt units on mainland Scotland. Now the Western Isles are self-sufficient in salmon smolts and, from 1988, has

exported its surplus to Shetland. They are in demand because Western Isles smolts have remained free of Furunculosis, the disease plaguing many of the larger mainland smolt units drawing their water from rivers containing migratory salmonids.

Rearing Techniques for Rainbow Trout

A brief technical description of freshwater cage culture of rainbow trout is given by Harvey (1988) in a chapter in Laird and Needham's book "Salmon and Trout Farming". The process is extremely simple.

Site Selection

Cages should ideally be moored in at least two pen depths of water within convenient reach of a floating jetty or similar easy means of access. A fetch in excess of 1 km in the general direction of prevailing winds is preferred to give adequate water circulation. Lake loading calculations usually dictate that the lake should exchange its total volume of water at least once a year.

Moorings and Cage Types

Provided there is sufficient space single point moorings are preferred. These enable the cage group to swing freely to orientate with the wind and cut down on any concentrated bottom pollution. The most common cage type in use in freshwater in Scotland is the square Kames cage (Figure 1).

Figure 1 shows a wooden framed cage with 6 metre long sides and wooden slatted walkways on two of the sides. Flotation is provided by polystyrene blocks and the nets are suspended from stays raised 1 metre above water level. Typically, the nets are some 5 metres deep below the water level giving an operating volume of approximately 130 m^3. Mesh size varies from 5 mm across the square for trout of up to 25 grams to 12 mm for trout of 25 grams or above. The fish are protected from bird predators by top nets of 7.5cm^2 stretched across the cage.

Rearing Process

Typically, underyearling trout of 5 grams or more are stocked in their first summer, and they are grown through to 50 - 100 grams (depending on water temperature) by the following April/May to maximum stocking densities of 20 Kg/m^3. Then they are thinned and ideally graded every 6 to 8 weeks to remove market sized fish of 250 grams or more and to set up populations of even size.

The typical Kames cage of 130m^3 can hold up to 2.5 tonnes of trout using maximum stocking densities of no more than 20 Kg/m^3. A typical process would be as follows:

June/July
Stock each cage with 30,000 fish at 5g (150 Kg)
Grow to 50g, 27,000 fish (1,350 Kg)

April/May
Grade and split between two cages. For example:
8,000 @ 70g (560 Kg)
19,000 @ 30g (570 Kg)
Grow both cages through to a maximum of 2,500 Kg.

Figure 1. Group of 6 Kames Cages (each 6x6 metres) in a Scottish freshwater loch.

Harvest off the top by grading approximately every 6 to 8 weeks. In this way, by allowing the fish to grow into available space, between June and May the following year each cage should yield approximately 3 tonnes of trout averaging 250 g. Because of this, the Kames 130 m^3 cage has become known as the 3 tonne cage.

Rainbow trout are harvested every month of the year. In the average Scottish freshwater cage farm, peak harvests are in the summer and early autumn from July to the beginning of October when maximum growth occurs and populations have to be repeatedly thinned to keep below peak biomass of 2.5 tonnes/ cage.

In the large Scottish Lochs like Loch Earn and Loch Awe the mean monthly water temperature at 1 metre depth will vary from 20°C in February to 140°C in July. Under these conditions, the farmer can expect to harvest half his crop in the 4 months June to September and the other half in the 8 months October to May. Fortunately, this pattern corresponds with summer seasonal demand for trout. It can be altered by intensifying grading and feeding, and keeping fish at reduced stocking densities to increase growth. Alternatively, populations can be held back and stored by restricting the feed.

Overall mortalities in an average farm even in the presence of Bacterial Kidney Disease are about 10% per year. All the large Scottish trout farms have this disease due to infection from a common source of fry and continuous cultivation with no fallow periods over many years. The only other important diseases are ***Costia*** which responds readily to formalin treatment, and ***Saprolegnia*** fungus which can take hold following rough handling during grading or net changes, or following fin rot due to overstocking.

All farms use "low phosphate" dry feed to minimize pollution (see loading calculations later). Typically, 80% of the feed is provided by auto-feeders and 20% by hand feeding. Hand feeding is regarded as essential to keep the farmers in touch with their fish and cater for the feeding bursts that occur at each end of the day.

Once established, the whole process is extremely simple. The activity consists primarily of taking feed out and grading and harvesting fish interrupted with occasional net changes when fish grow through the critical 25g size. Biofouling of nets is not normally a problem in the cold nutrient poor freshwater lochs in Scotland.

Rearing Techniques for Atlantic Salmon

As there is no published text available describing freshwater cage rearing techniques for Atlantic salmon, the information had to be taken first hand from working experience within Landcatch Ltd. and North Uist Fisheries in Scotland. It is supplemented by data from Marine Harvest Ltd. and Sea Farm A/S of Norway.

The 6 Month Process

This is the technique developed by Landcatch Ltd. in Scotland who raise some 2 million smolts a year for third party sales. They raise the fish initially in conventional 3.6m diameter Fiber-glass tanks from first feeding until the large fraction of the population reaches some 12g to 15g by mid-September. These fish are graded out and are identifiable as potential yearling smolts (Sl) by their size.

In good high temperature years some 80% of the fish make the top grade and become Sls. Between September and November the graded large fish are helicoptered to cages in freshwater lochs. Landcatch use the 6m X 6m Kames cage with nets 5m deep. The mesh size is 5mm (on the square) and the fish are stocked at 20,000 per cage. They are overwintered and grown in the cages right through to smolting at 45g to 80g with maximum stocking densities not exceeding 10 Kg/m^3. The Landcatch lochs have a particularly high flow and turnover; one of them, the Jura loch, changing its water volume on an average once every 10 days. Other companies with the slow moving lochs that may exchange only 1 to 2 times a year prefer to operate to maximum stocking rates of 5 Kg/m^3. North Uist Fisheries, for example, stock their 130m^3 Kames cages at 10,000 as opposed to 20,000 fish per cage for this reason.

Some 95% to 99% of the fish survive to smolt the following year. Principle causes of any fish loss are usually fin rot and ***Saprolegnia*** fungus. Usually more fish "disappear" through unaccounted losses or inventory shrinkage than are recorded as mortalities.

The main advantage of this 6 month process is that the fish do not have to be graded in the difficult and often remote environments. They have already been preselected as potential yearling smolts. The other advantage is that the site is "fallowed" for up to 6 months between year classes. This effectively prevents any disease carryover. Also, it allows phosphate and other nutrient concentrations to return to base levels and any bottom deposition to be assimilated. It is useful that there is no nutrient input at high summer temperatures when algal blooms could arise.

Marine Harvest 12 Month Process

Marine Harvest have attempted rearing Atlantic salmon fry from first feeding onwards in freshwater cages. Some success was achieved using shallow nets of 2m deep and mesh sizes of 2mm. Each of their standard 7.3m X 7.3m wooden cages was stocked with 100,000 fry. Unfortunately, the nets were too easily occluded by algae and had to be changed every 7 to 10 days. Also, there were severe accountability problems as it was found to be impossible to accurately count the mortalities. In the first 6 weeks of feeding mortalities could reach 80%.

Instead, Marine Harvest now stock the cages with fed salmon fry at a minimum weight of 0.5g. Whilst this is a low capital cost route to expanding smolt production, it does have the considerable disadvantage that the yearling smolt percentage can be reduced to 30% or less. Landcatch find by raising the fish for their first 6 months in tanks they can achieve a yearling smolt percentage of at least 70%.

The problem with starting salmon fry earlier in freshwater cages is that the husbandry is more at arms length. Feeding is less exact because the fish are invisible most of the time. Also, the temperature 5 metres down in a freshwater lake is generally below the temperature of the surface run-off water usually used by an Atlantic salmon tank unit in Scotland. Early growth is poorer in cages in the cool lochs leading to a lower S_1% compared to fish reared through this crucial early stage in tanks.

Another big advantage of early rearing in tanks is that it is possible to grade if necessary every 3 to 4 weeks to cream off the top and allow more potential yearling smolts emerge from the middle fraction. In this way, grading actually influences the final percentage of yearling smolts. Unfortunately, it is not possible to grade nearly so often in freshwater cages. In contrast to rainbow trout at the point of harvest where fairly crude hand grading systems suffice, more sophisticated machinery is required to grade small salmon in the 0.5g to 15g weight range. It is simply not possible to use such automatic graders at remote cage sites with no power sources.

Marine Harvest found that on some sites grading was impossible. All they did was to separate S1 smolts from parr by hand at smolting time. They have considerable difficulties forecasting what their final smolt numbers would be and find themselves most years either buying smolts to make up their requirements and selling their surplus.

Under the Landcatch 6 month system proven over the last 5 years on average it has taken 2 eyed salmon eggs to produce one yearling smolt. Under the Marine Harvest 12 month system, it takes 4 eyed ova on average to produce each yearling smolt.

Raising 2 Year Old Smolts

There is little requirement for two year old smolts in the Scottish salmon farming industry. They attract a similar price to S1s and, therefore, leave little, if any, margin for the smolt producer. They have lived longer and are more likely to have contracted and be carrying diseases like Furunculosis and Bacterial Kidney Disease. Most important of all they are the slower growing fraction in freshwater. Growth in freshwater appears to be correlated with growth potential in the sea and two year old smolts tend to have a lower daily specific growth rate in seawater cages. The initial size advantage provided by their larger size at seawater entry and their earlier transfer is usually lost by the time the fish are harvested. Worse still, two year old smolts tend to give a higher grilse percentage than yearling smolts.

According to D.A.F.S., only 6.5% of the smolts that went to sea cages in 1989 were S2s. All the larger concerns like Marine Harvest, McConnel Salmon, and Landcatch discard their potential S2s as soon as they are identifiable. This leads to considerable wastage in the 12 month freshwater cage process as operated by Marine Harvest.

North Uist Fisheries is one of the few Scottish companies still persevering with S2 smolts for sale. They are raised for 9 to 12 months in tanks until the last possible S1s can be graded from them. They are then grown in cages for up to another 12 months until they smolt.

Several S2 sites have been developed. These are generally brackish water lochs at sea level which have some tidal egress and where the salinity does not exceed 22 parts per thousand. S2s are particularly prone to *Saprolegnia* fungus which infects the precociously mature males that arise during the winter prior to smolting. Salt water influence at 15 parts per thousand or above effectively controls *Saprolegnia* fungus.

One company, Lighthouse of Scotland, operates an estuarine site where they specialize in growing potential S2s. They claim that winter growth is enhanced because their brackish water temperatures are warmer than in full freshwater.

Commercial Rationale for Freshwater Cage Culture: Trout

There is no published evidence that raising trout in freshwater cages is any cheaper than other systems. However it is clear that with the expansion of freshwater cage culture in Scotland, it is the most cost effective way of raising trout on a large scale. Of the five largest farms producing over 200 tonnes of trout in 1989, four were freshwater cage farms, (D.A.F.S. Statistics). All have been in existence for at least 10 years. The one non-cage farm raising over 200 tonnes of trout is an earthen pond farm, Kenmure Fisheries, constructed 21 years ago.

In contrast, the one 200 tonne plus concrete raceway farm built in Scotland by a company Gateway West Ltd. went into receivership after five years of operation in 1982. The high capital costs could not be justified.

There are other less obvious benefits accruing from a freshwater cage farm. The basic infrastructure of shore base, shore to cage link, staffing, and overheads can serve a cage farm of varying production capacity. All that has to be added are more cages and nets and the people to work them. In contrast, a tank or pond farm has a water supply system which is limiting. Extending the farm beyond the original design specification requires considerable extra water supply costs even if it is possible. Limitations on the water source and disposal of effluent ultimately restrict all tank and pond farms to a given size. A cage farm has greater scope for expansion in a large water body. This is why the largest trout farms in Scotland are cage farms. They have the advantages of economy of scale over other trout farms. The marginal costs of increasing capacity are less.

After all salmon and trout farming probably utilizes more water per unit of production than any other manufacturing process. Cage rearing represents the cheapest way of getting water to the fish.

Commercial Rationale for Freshwater Cage Culture: Salmon

Shaw and Muir (1987) in their book "Salmon: economics and marketing.", published a table comparing the unit costs of raising yearling Atlantic salmon smolts in a conventional tank farm and freshwater cages. Their results are summarized in Table 4:

Table 4: Estimated Costs of Each Atlantic Salmon S1 with Different Rearing Strategies (Canadian Dollars)

Annual Production (Number of smolts)	100,000	200,000
Tank farm	1.64	1.26
Cage farm	1.44	1.10

Source: Modified from Shaw and Muir (1987).

In both case studies, it was some 13% cheaper to raise S1 Atlantic salmon smolts in freshwater cages than in tanks. Unfortunately, as the cost breakdowns are not given, it is impossible to calculate from their data what benefits economy of scale would give in much larger cage farms. The smallest cage farm operated by Landcatch Ltd. has an annual output of 450,000 smolts. Their largest farm has produced 650,000 smolts. It is likely that the rearing costs of Landcatch smolts are considerably less than the figures presented in Table 4.

Shepherd (1988) in Shepherd and Bromage's "Intensive Fish Farming" gave unit costs of production for S1 salmon smolts reared in a tank farm as outlined in Table 5. All values are adjusted to Canadian dollars and, like Shaw and Muir (1987), represent 1987 costs.

Table 5: Effect of Scale on Atlantic Salmon S1 Production in a Tank Farm
(Canadian Dollars)

Annual Smolt Output	120,000	500,000
Capital Costs		
1. Hatchery, Tanks, etc.	260,000	800,000
2. Annual depreciation (20 yrs)	13,000	40,000
Operating Costs		
3. Egg purchases	26,000	100,000
4. Labour	66,000	114,000
5. Feed 14,000	52,000	
6. Miscellaneous	18,000	64,000
TOTAL 124,000	330,000	
7. Annual Interest on Capital at 14%	36,400	112,000
8. Annual Interest on Expenditure Balance	10,000	24,000
TOTAL 46,400	136,000	
TOTAL OPERATING	183,400	506,000
Capital Costs/Smolt	2.17	1.60
Total Operating Costs/Smolts	1.52	1.01

(Modified after Shepherd, 1988)

Shepherd's (1988) basic assumptions were:

- Gravity water supply with no dam or pumping.
- Egg purchase costs at $88/1,000 (small scale) and $80/1,000 (large scale).
- Labour: manager + 1 labourer (small scale)
  manager + 3 labourers (large scale)
- Feed: 10 tonnes usage at $1,400/tonne (small scale)
  41 tonnes usage at $1,268/tonne (large scale)

In these two case studies, the capital costs per smolt produced are:

- $2.17 for the 120,000 smolt unit
- $1.60 for the 500,000 smolt unit

The unit costs of production are cut by $0.57 per fish or 26% by operating a 500,000 smolt unit as opposed to a 120,000 smolt unit.

Banks and Needham (1986) conducted a study on standardized Atlantic salmon smolt units for the New Brunswick Department of Fisheries. The financial analysis was based on experience with Sea Farm A/S in Scotland and New Brunswick and Landcatch Ltd. in Scotland. In addition, the model was based on producing 75% S1s and 25% S2s and employed high technology systems with heat exchangers, etc., to cater for the cold New Brunswick winters.

The calculated unit costs per smolt are shown in Table 6.

Table 6: Basic Cost/Smolt After 4 Years Operating New Brunswick Model Smolt Unit

Annual production (# of smolts)	100,000	200,000	500,000
Unit cost/smolt (Canadian $) (From Banks and Needham 1986)	2.06	1.68	1.50

These figures are up to 48% higher than those of Shepherd (1988) despite being calculated two years earlier. This reflects the greatly increased capital costs of the Banks and Needham (1986) model, and the extra expense of raising S2s.

Adapting Shepherd's (1988) simple model to a 6 to 9 month freshwater cage system, the following assumptions are made:

- Fish raised from egg to 15 grams for 9 months February to October in the tank site which is then emptied and cleared until the next eyed egg intake in February.
- The fish are raised for another 7 months in freshwater cages.
- Staff are common to both units and are the same as in the Shepherd model.
- Total feed usage is the same.
- Cage site capital costs ($) are as follows:

120,000 unit:	
6 cages at $3,000/cage, net, moorings-	18,000
1 small boat plus outboard -	5,000
1 feed storage hut -	2,000
500,000 unit:	
25 cages at $3,000 -	75,000
2 small boats plus outboard -	10,000
1 large feed storage hut -	5,000

In addition, each site would have miscellaneous capital works for a small floating jetty, access, etc., estimated at $20,000 per site. This would be depreciated over 10 years. All other capital equipment would be depreciated over 5 years.

In constructing a new model based on a hatchery followed by freshwater cages, it is important to note that the capital costs of the hatchery are reduced by 66% because the fish are only being raised to 15g instead of 45g.

Table 7: Combined Hatchery (9 months) and Freshwater Cage Site (7 months) (Costs in Canadian Dollars)

Annual Smolt Output	120,000	500,000
Capital Costs		
1. Hatchery, tanks, etc.	86,666	266,666
Annual Depreciation over 20 yrs.	4,333	13,333
2. Cages, boat, hut, etc.	25,000	90,000
Annual Depreciation over 5 yrs.	5,000	18,000
3. Site works	20,000	20,000
Annual Depreciation over 10 yrs.	2,000	2,000
TOTAL CAPITAL	131,666	376,666
TOTAL ANNUAL DEPRECIATION	11,333	33,333
4. Operating costs	124,000	330,000
5. Interest on Capital at 14%	18,433	52,733
6. Interest on Expenditure balance	10,000	24,000
TOTAL OPERATING	163,766	440,066
CAPITAL COST/SMOLT	1.10	0.75
TOTAL OPERATING COST/SMOLT	1.36	0.88

Combining the Shepherd (1988) model and the joint hatchery and freshwater cage model described in table 7, the likely cost savings of freshwater cages become obvious (Table 8).

Table 8: Comparison of Tanks and Freshwater Cage Rearing Costs for Atlantic Salmon
(Canadian Dollars)

	Tank Farm (Shephard 1988)		Hatchery/Cage Combined	
Annual Smolt Output	120,000	500,000	120,000	500,000
Capital Cost/Smolt	2.17	1.60	1.10	0.75
Total Operating Cost/Smolt	1.52	1.01	1.36	0.88

It is obvious from these two simplistic models that it is 11% to 13% cheaper to raise Atlantic salmon smolts in freshwater cages rather than growing them right through in tanks. This is because the capital cost per smolt raised in cages is about half of that for smolts raised in tanks. As the capital costs are so low the marginal costs of expanding output are far lower in a system employing freshwater cage grow-out facilities.

The main cost differences between the two systems is cost of capital. Therefore relative differences are extremely sensitive to interest rate changes. At a time of high interest rates, the cost of capital takes up a greater proportion of the cost of production (Table 9).

Table 9: Sensitivity of Unit Smolt Costs to Interest Rates Hypothetical 500,000 Smolt Production Model
(Canadian Dollars)

Interest Rate	8%	14%	20%
Tank only	0.90	1.01	1.12
Tank and Cages	0.81	0.88	0.95

As the tank system is more capital intensive, smolt costs using the hatchery method are more sensitive to interest rate changes. In times of high interest rates, it makes even more sense to grow out potential smolts in freshwater cages.

Conflicts

The local authority planning system is set up to resolve conflicts as may be engendered by a freshwater cage application. The elected local councilors who take the final decision to approve or reject, and set the appropriate planning conditions are advised by professional planners and legal expects employed by the local council.

As already stated the local authority is obliged to consult the local River Purification Board to establish the discharge consent and permissible fish biomass. Invariably other advisory bodies are consulted, such as:

- Nature Conservancy Council
- District Salmon Fishery Board
- Highways and Drainage Authority
- Water Services Departments managing drinking water
- Department of Agriculture and Fisheries for Scotland.

The local councillor for the area will often consult local people through community councils and invite the applicant to present his case. It is at this point that local anglers are often reassured that there is no threat to their interests. Fish farmers have been known to make local restocking and enhancements arrangements beneficial to angling interests.

Although it is often presented nationally that there are conflicts between conservation interests and freshwater cage farming, this rarely happens at the local level. This is partly because all freshwater lochs in Scotland have single or shared ownership. The fish farmer gains entry through a rental agreement and has the owner's active support. He cannot farm in the loch or establish a shore base without such an arrangement.

Some corporate owners like the North of Scotland Hydroelectric Board have been cautious to give their consent. They are concerned that groups of cage moored in their lochs could break loose and damage their facilities. Accordingly they require the fish farmer to carry heavy indemnity insurance.

In 1989, the Hydro Board anxious to avoid public controversy in the run up to privatization placed a moratorium on all further leases for freshwater cage operators for 2 years. In the interim they are carrying out a water quality monitoring exercise with Marine Harvest Ltd. at their large smolt cage site at Loch Garry. Already they have shown that any seasonal change the fish farm may have made to the nutrient status of the water has been totally masked by phosphate used on nearby commercial forests.

Water Quality

When the bathymetry of the loch is carried out at the site selection stage, it is usual to take oxygen and temperature depth profiles, particularly in the deepest parts of the loch. If there is any seawater egress it is important to take salinity profiles as well to try and gauge the age of the bottom low salinity layers. Older deeper water can be anoxic and contaminated with polluting hydrogen sulfide.

Other site measurements include the following:

Sechii disk to measure turbidity
pH
Alkalinity and conductivity

Preserved samples are further analyzed for nitrogen and phosphorus compounds and a range of common metal pollutants. Additional analysis depends on surrounding land use. For example, the B.O.D. of any inflowing streams from silage pits or other intensive agricultural activities must be checked. Abandoned cars are a source of toxic lead from decaying batteries. Any effluent from worked out mines should be tested for mercury, cadmium, zinc, copper and other dangerous heavy metals.

The major water quality parameters should fall into the range commonly accepted for salmonid growth. Those found in Piper (1986) are reproduced in Appendix 1. Particular water quality problems have arisen from the following in Scotland.

Periodic Acidity

Many upland Scottish lochs are sited on Precambrian rock. This leads to low conductivity water with extremely low buffering capacity. At times of acid snow melt or even salt storms in those lochs within 30 km of the sea there can be catastrophic reductions in pH. Should it drop to 4.5 or below even for a 24-48 hour period the fish become more susceptible to aluminum, iron, and other heavy metals. In the case of toxic aluminum levels over 0.2 mg/l^3, smolting can be impaired.

With so many Scottish lochs now occupied by salmon and trout in freshwater cages, considerably more is being learned about seasonal variations in water quality. In parts of Scotland episodic declines of pH were first recorded because there were farmed fish present. They are now thought to have an important influence on the wild fishery resource. In this case, farmed fish have acted as canaries, monitoring the water quality on behalf of wild fish.

Humic Acids

Many Scottish lochs are set in peat. The peat gives water a pronounced brown colour which can become more intense during heavy run off. This makes husbandry difficult as the fish are rarely seen and feeding becomes less accurate. In addition, it is possible that smolting can be delayed slightly in the reduced light conditions.

The main advantage of coloured water of high turbidity is that the risk of algal blooms due to phosphorus enrichment is low. This is probably why some cage farms in Scotland are able to prosper in Scottish lochs where phosphorus levels exceed 40 mg/m^3 because of agricultural and forestry run off. If the water was clearer there would be the hazard of seasonal algal blooms with consequent problems of deoxygenation and possible toxicity.

Ice Cover

Most Scottish freshwater lochs are selected for cage culture simply because they remain ice free. Unfortunately in exceptionally cold years some have frozen and ice flows have caused considerable damage at ice melt. One farm on Knoydart estate near Fort William was totally destroyed in the winter of 1979 when ice melt coincided with strong winds.

In Norway techniques have been developed for growing salmon smolts in freshwater lakes with ice cover. Sea farm A/S use slow moving large propellers under the cages to draw up warmer water and keep the cages ice free. The propellers also serve to promote mixing and water cooling in the heat of the summer. Systems of ice management using booms have been developed by the Norwegians along similar lines as practiced by the sea farms of parts of eastern Canada.

Disease Risk of Freshwater Cage Culture in Scotland

The Department of Agriculture and Fisheries for Scotland state unequivocally that there is no evidence of disease transfer from farmed fish in freshwater cages to the wild stock (McVicar, personal communication).

Not surprisingly, as all disease of farmed fish originate from wild fish in the first place, there is abundant evidence of lateral disease transfer from wild fish to farmed fish in cages. Wooten (1979) found that rainbow trout reared in cages could become severely infected with the tapeworms ***Triaenophorus nodulosus*** and ***Diphyllobothrium*** spp. Infections were so bad as to force the closure of one farm. Wild fish were found to be carrying the parasites which were then spread to the farmed trout via infected copepods.

Matheson (1979) found that in one freshwater loch Atlantic salmon parr became infected with ***Diphyllobothrium ditremum*** and ***D. dendriticum*** within two months of being stocked in the cages. Phillips et al. (1983) believed that the farmed salmon ate the infected copepods because they were underfed.

There are many anecdotal reports in the industry of farmed Atlantic salmon smolts from sources demonstrably free of the particular pathogens becoming infected with Bacterial Kidney Disease and even Furunculosis once they have been transferred to freshwater cages. Similarly rainbow trout raised at known E.R.M. free sites have been known to contract the disease once in freshwater cages (McVicar, personal communication).

Certainly ectoparasitic protozoa like ***Costia*** and ***Trichodina*** have arisen de novo on salmon and trout in freshwater cages. They could only have come from the wild fauna.

Controls on Freshwater Cage Farms in Scotland

Legislative Framework

The local Authorities in Scotland are charged under the Town and Country Planning (Scotland) Act 1972 with granting or withholding planning or rezoning consent for freshwater cage farms. This was made clear in circular 8/1990 issued by the Scottish Development Department on 22 March 1990. Previously there had been some doubt as freshwater cage farming had been considered by the industry to be a branch of agriculture and therefore not subject to tight planning controls.

In the circular, Graham (1990) stated that prior to determination of the planning application local authorities are advised to consult:

- The District Salmon Fishery Board who represent the owners of salmon fisheries in the watershed. They would be invited to comment on the impact of the proposed fish farm on wild fish stocks.

- The Local River Purification Authority for advice on discharge and effluent levels. Under the Water Act 1989 Fish Farms must also have the consent of the River Purification Authority who may impose conditions which would be embodied in the planning consent and legally enforceable. Furthermore, the Authority may carry out monitoring and sampling to check compliance. Failure to comply may lead to revocation of the planning concept as well as fines imposed by the Courts.

- The Nature Conservancy Council where there is a potential conflict with a designated wildlife reserve.

The Secretary of State for Scotland justified these changes in a consultation document (ref. A 0400703.089) issued by the Scottish Development Department in 1989. He said that local authorities must have control over fish farms so that environmental aspects can be adequately considered. These include:

- discharge and effluent levels,
- siting, especially in areas of landscape and scenic beauty and proximity to Nature Reserves,
- impact on wild salmon stock.

Guidelines for Local Authorities

Aesthetics

The guidelines on siting and appearance were drawn up as a result of a study by the Countryside Commission, the Crown Estate Commission, the Highlands and Island Development Board, and the Scottish Salmon Grower Association. Although the study was aimed principally at marine cage farms the guidelines are applied equally to freshwater. They are summarized by Martin (1987) as follows:

1. When selecting a site, find out at an early stage whether any special landscape designation applies - if so, attention should be given to landscaping during project planning.

2. Consider how visible the site will be to the public by systematically examining maps, visiting viewpoints and taking photographs; views from tourist routes and high level views which make sites visible from a great distance are particularly important.

3. Make plans to reduce the visibility of the site if it is likely to be prominent from major public viewpoints; if no existing screening is available for land based structures consider new screening measures such as tree planting, fencing, walling and ground modeling.

4. Where possible, position cages at a distance from major viewpoints and against a backdrop of land which may offer partial camouflage.

5. Avoid tall and complex structures in open settings and on cages.

6. When choosing equipment such as nets, feed hoppers and walkway coverings, select dark, subdued, non-reflective colours and materials; use brightly coloured floats and markers only where required for safety or navigational reasons.

7. Where possible convert existing buildings rather than building new ones; for new buildings choose designs and materials that fit in with local architecture.

8. Where possible avoid large, regular geometric representations of tanks or cages in favour of patterns related to landform or shore configuration.

9. Minimize the impact of temporary buildings through careful siting, grouping and colouring.

10. Minimize outdoor storage of materials and equipment; where outdoor storage is essential provide a fenced or screened compound; ensure proper disposal of litter, debris and unused equipment.

11. For onshore installations make provisions for maintenance of grassed and treed areas, walls and fences; where new access tracks have been created reinstate road verges.

Wild Salmon Populations

The owners of salmon rights within the District Salmon Fishery Board almost invariably object to freshwater farms in their watersheds on the grounds of the risk of disease introduction and possible genetic pollution from escapees. These objections are usually overruled by the planning authority who will only normally refuse consent if there are particularly strong aesthetic considerations or the River Purification Board are unable to grant a discharge consent. The Department of Agriculture and Fisheries for Scotland (DAFS) repeatedly advise local authorities that there has never been any evidence of an epidemic or clinical disease outbreak amongst wild fish in Scotland originating from a fish farm (McVicar 1990). The movement of fish with noticeable disease is expressly forbidden under the Disease of Fishes Act 1983 which is rigorously and effectively enforced by DAFS. The Planning Authorities give little weight to any disease risk from freshwater cage farms as a result. The risk of escapes is covered as part of the planning conditions which require the nets to be regularly inspected and kept escape proof, and the insistence on predator nets around the outside of the cages and secure bird nets over the top.

Discharge Consents

Under the Control of Pollution Act (1974) the Scottish River Purification Boards have power to control the discharge of organic or toxic wastes. All the Boards in Scotland are agreed that effluent from a freshwater cage farm is a trade effluent and therefore requires a discharge consent. Although the discharge from freshwater cages cannot be measured as a point source, it can be calculated. The impact of a freshwater cage farm on water quality is calculated on the basis of its effect on the phosphorus concentration because phosphorus is the main limitation on the nutrient status of freshwater lochs (Phillips et al., 1985).

Interestingly, nitrogen is regarded as the most important nutrient from marine fish farms. Detailed calculations from the Norwegian salmon farming industry indicate that the total discharge of nutrients from a marine farm with a carrying capacity of 50 tonnes would correspond to the discharge from a sewage purification plant from a town of about 7000 inhabitants (Hakanson et al., 1988).

The River Purification Authority calculate how much phosphorus a particular loch can carry before it becomes eutrophic. This means that they are prepared to consent to a given biomass of farmed fish sufficient to keep the phosphorus levels in the loch below 20 mg/m^3. Eutrophic is defined by the authorities as being above 20 mg/m^3 (Table 10).

Table 10: The relationship between water phosphorus concentration and water quality in static freshwaters.

Total phosphorus concentration (mg/m^3)	Water quality characteristics
<10	Nutrient poor, unproductive lochs with a generally low level of algae. Ideal lochs for fish farming and other water users. Typical unpolluted Scottish "oligotrophic" or "dystrophic" waters.
10-20	Intermediate water quality characteristics between "oligotrophic" and "eutrophic", commonly classed as "mesotrophic". Water quality variable with the possibility of visible algal growth. More productive than above but still usually suitable for salmonid cage culture.
>20	Productive "eutrophic" waters, with common summer algal blooms, particularly of blue-green algae. Less suitable for salmon cage culture.

(Source, adapted from Phillips et al., 1985).

The Carrying Capacity Calculation

The theory behind lake carrying capacities based on phosphorus concentrations is explained in detail by Beveridge (1986) in the FAO Fisheries Technical Paper no. 255.

Beveridge highlights the difference between the reccomended phosphorus requirement of salmon set at 0.3% of the diet by Ketola (1975) and the actual level of phosphorus in commercial dry pellets at 1.4-2.2% (Ketola 1982). Salmon and trout feeds are high in phosphorus simply because they contain large quantities of bone meal. Low phosphorus salmon food is available experimentally in Scotland with phosphorus levels reduced to 1.5% with the aim of cutting down the excess released into the environment. As such pellets are made up of plant protein like Soya supplemented with amino acids and are likely to be more expensive than those currently available.

Theoretical calculations on the total phosphorus released into the environment from freshwater cage culture of trout can vary as follows:

Phosphorus content of commercial pellet = 1.5%

1 tonne feed contains = 15.0 Kg phosphorus

At a Feed Conversion rate

FCR of 1.0:1. Phosphorus Fed = 15.0 Kg

FCR of 1.5:1. Phosphorus Fed = 22.5 Kg

FCR of 2.0:1. Phosphorus Fed = 30.0 Kg

But, according to Penczak (1982), the phosphorus content of a trout

= 0.48% of the wet weight of the fish

= 4.8 Kg/tonne fish.

Therefore, phosphorus release to the environment per tonne of fish produced is expected to be the following:

FCR 1.0:1. 15.0-4.8 Kg	= 10.2 Kg phosphorus
FCR 1.5:1. 22.5-4.8 Kg	= 17.7 Kg phosphorus
FCR 2.0:1. 30.0-4.8 Kg	= 25.2 Kg phosphorus

The principle losses of excess phosphorus to the surrounding water are summarized by Beveridge (1984) as follows:

- direct from the feed
- uneaten pellets
- fish feces
- fish urine

The model that Beveridge (1986) suggests and is used by the Scottish River Purification Boards is as follows:

$$[P]\ i = \frac{Tw \times L \times (1-R)}{Z}$$

where [P] i = increase in phosphorus concentration in mg/m^3 due to fish in the cages.

Tw = water retention time in the loch in years

L = soluble phosphorus loading rate in $mg/m^2/yr$

R = sedimentation coefficient or fraction of soluble phosphorus sedimented to the sediments.

Z = mean depth of the loch in metres.

Rearranging for L to give the soluble phosphorus loading rate:

$$L = \frac{([P]\ i \times Z)}{Tw \times (1-R)}$$

This equation is described as Dillon and Rigler's (1974) loading model for freshwater modified from Vollenweider (1966).

The step by step approach to using the model is as follows:

Step 1 - Establish the maximum permissible phosphorus loading.

As already stated the maximum phosphorus level generally permitted in the naturally oligotrophic lochs in Scotland is 20mg phosphorus/m^3. If the base level in the loch is measured at say 9.7 mg/m^3 (ideally at the time of Spring overturn when the water is likely to be well mixed and less Phosphorus is incorporated in the algae populations concentrated at different depths).

[P]i = 20.0-9.7 = 10.3 mg/m^3

Step 2 - Measure hydrographical and other important variables

Water retention time

This is calculated by measuring the total area and estimating the mean depth using echosounding to construct a bathymetric chart. In this way the total water volume can be estimated.

The total area of the catchment is then computed with the mean annual rainfall gathered from local meteorological data to give the total water input.

From this is subtracted the annual evapo-transpiration rate which is usually available from local forestry interests. In most afforested areas of Scotland where freshwater cage sites predominate the evapo-transpiration rate in calculated at 0.45m per year.

Taking a worked example of a Scottish West Coast freshwater loch the morphometric data is as follows:

- Surface area calculated from ordinance survey map = 20.25 hectares
- Mean depth calculated from a bathymetric survey = 11.22 metres
- Therefore volume = 2.27 X 106 m^3
- The catchment area calculated from the ordinance survey map = 9.125 X 105 m^2
- The mean annual rainfall from local meteorological data = 1.287 m.
- The estimated annual evapo-transpiration = 0.45 m.
- Therefore the amount of water flowing into the loch = 7.6376 X 105 m^3
- As the volume = 2.27 X 106 m^3
- The exchange rate = 0.34 per annum
- Retention time Tw = 2.975 years.

Step 3 - Sedimentation Coefficient (R)

The fraction of phosphorus trapped within the sediments depends on the water residence time and the mean depth of the loch.

Empirical measurements at Stirling University have suggested the following relationship (Phillips, personal communication).

$$R = 0.426 \exp(-0.27/ga) + 0.571/\exp(-0.00949\ ga)$$

where ga = hydraulic load = $\frac{\text{mean depth in metres}}{\text{water retention time in years}}$

In the previous example mean depth = 11.22 metres

and water retention time = 2.975 years

Therefore, the hydraulic load (ga) = 3.7714

R can be recalculated by substituting 3.7714 into the equation:

Sedimentation coefficient R = 0.71

Therefore, 71% of the phosphorus passes into the sediments and only 24% is flushed away.

Step 4 - Caged Fish Loading (L)

The equation is:

$$L = \frac{([P]\,i \times Z)}{(Tw \times (1-R))}$$

[P] i, the allowable increase in phosphorus = 10.3 mg/m^3

Z, the mean depth = 11.22 metres

Tw, the retention time = 2.975 years

R, the fraction of soluble phosphorus retained = 0.71

$$L = \frac{10.3 \times 11.22}{2.975 \times (1-0.71)} = 133.95 \text{ mg phosphorus/m}^2\text{/yr.}$$

Thus the permissible loading rate is 133.95 mg.P/m^2/yr.

Recent work at Stirling University (Phillips, personal communication) has suggested that the output of total phosphorus per tonne of Atlantic salmon smolts to be as follows:

FCR 1.5-1 - 14 kg phosphorus/tonne of salmon smolts.

FCR 2.0-1 - 20 kg phosphorus/tonne of salmon smolts.

It is not appropriate to use this total loading in the model equation because more than 50% is lost immediately as solid material to the sediments below the cages. According to Phillips (personal communication) less than 2% of this solid waste is returned into the water column from the sediments.

The "safe" and pessimistic estimate used by the Stirling workers which is born out by their observations is that the maximum possible soluble phosphorus discharged would be 8.3 kg soluble phosphate/tonne of salmon smolts (Phillips, personal communication).

To apply this loading estimate of 8.3 kg soluble phosphorus/tonne of fish to the loch in question it needs to be:

a) Divided by the surface area of the loch (2.025×105 m^2)
b) Multiply by 106 to convert from kg to mg

to give the loading in mg phosphorus/m^2 loch/tonne of fish.

Therefore in the loch in question each tonne of fish will yield

$$\frac{8.3 \times 10^6 \text{ mg phosphorus/m}^2\text{/year}}{2.025 \times 10^5}$$

i.e. 40.988 mg phosphorus/m2/year

But the allowable loading L = 133.95 mg phosphorus/m^2/year.

Therefore allowable tonnage = $\frac{133.95}{40.988}$ = 3.268 tonnes

Therefore 3.268 tonnes of salmon can be raised in the loch in a year or 6.536 tonnes in 6 months, i.e. 50 grams growth per smolt in 6 months.

The total rearing capacity of the loch = 130721 smolts over a 6 month cycle.

Because these calculations are complex and are founded on criteria established by Phillips and his group at Stirling University, the Scottish River Purification Boards invariably ask the prospective fish farmer to commission a report from Stirling University.

The discharge consent is based entirely on the Stirling observations. It will specify the maximum allowable biomass of fish the farmer is able to rear in the loch based entirely on the phosphorus loading calculations.

Discharge of Noxious Chemicals and Other Planning Conditions

In addition to setting the total biomass of fish in the loch the River Purification Board will ask the farmer to set down his proposed use of treatment chemicals, drugs, and antibiotics. These will then be detailed in the discharge consent. If the loch is being used as a source of potable water, the local authority may forbid the use of all these substances.

Most local authorities also require the farmer to monitor the water quality in and around the cages. Normally only dissolved oxygen and phosphorus are specified. This has led to the interesting anomaly that uncontrolled phosphate fertilization in commercial forests has given rise to far greater changes to the nutrient status of freshwater. Indeed in some cases forestry operations have raised the phosphate levels to beyond the eutrophic threshold of 20 mg/m^3. Fish farmers, not unnaturally, are concerned that the carrying capacity of their farms is effectively being set by the uncontrolled activities of others. As yet this problem is unresolved. Once a discharge consent is issued it remains inviolate.

Conclusions

* Freshwater cage culture started in Scotland in 1975
* By 1989, 42% of the Scottish trout were grown in 16 cage sites
* By 1989, 52% of the salmon smolts were raised in 70 cage sites
* Trout are raised typically in a 3 tonne Kames cage to 20 Kg/m^3
* Atlantic salmon S1s can be raised for 6-12 month periods
* S2 smolts are best raised in brackish water
* Four of the five largest trout farms in Scotland are freshwater cage farms
* It is cheaper by about 13% to raise trout and salmon in freshwater cages
* Capital costs are greatly reduced
* Freshwater cage farms require planning and industrial discharge consent
* The local authority consults widely before coming to a decision
* The discharge content specifies the biomass of fish that can be raised
* This is calculated from the phosphorus released
* Water quality problems include acidity, peat and ice
* There is no evidence of disease transfer from freshwater cage populations to wild fish in Scotland
* There is abundant evidence of disease transfer from wild fish to farmed fish in cages

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Appendix 1:
Water Quality Parameters For Salmonids

Table 1. Suggested water quality criteria for optimum health of salmonids fishes. Concentrationsare in parts per million (ppm). (Source: Wedemeyer 1977.)

Chemical	Upper Limits for Continuous Exposure
Ammonia (NH3)	0.0125 ppm (un-ionized form)
Cadmium	0.0004 ppm (in soft water < 100 ppm alkalinity)
Cadmium	0.003 ppm (in hard water > 100 ppm alkalinity)
Chlorine	0.03 ppm
Copper	0.006 ppm in soft water
Hydrogen sulfide	0.002 ppm
Lead	0.03 ppm
Mercury (organic or inorganic)	0.002 ppm maximum, 0.00005 ppm average
Nitrogen	Maximum total gas pressure 110% of saturation
Nitrite (NO2) nitrite-nitrogen)	0.1 ppm in soft water, 0.2 ppm in hard water (0.3 and 0.06 ppm
Ozone	0.005 ppm
Polychlorinated biphenyls (PCBs)	0.002 ppm
Total suspended and settleable solids	80 ppm or less
Zinc	0.03 ppm

Table 2. Suggested chemical values for hatchery water supplies. Concentration are in parts per million (ppm). (Source: Howard N. Larsen, Unpublished.)

Variable	Trout
Dissolved Oxygen	5-saturation
Carbon Dioxide	0-10
Total alkalinity (as CaCO3)	10-400
% as phenolphthalein	0-25
% as methyl orange	75-100
% as ppm hydroxide	0
% as ppm carbonate	0-25
% as ppm bicarbonate	75-100
pH 6.5-8.0	
Total hardness (as CaCO3)	10-400
Calcium	4-160
Magnesium	Needed for buffer system
Manganese	0-0.01
Iron (total)	0-0.15
Ferrous ion	0
Ferric ion	0.5
Phosphorus	0.01-3.0
Nitrate	0-3.0
Zinc	0-0.05